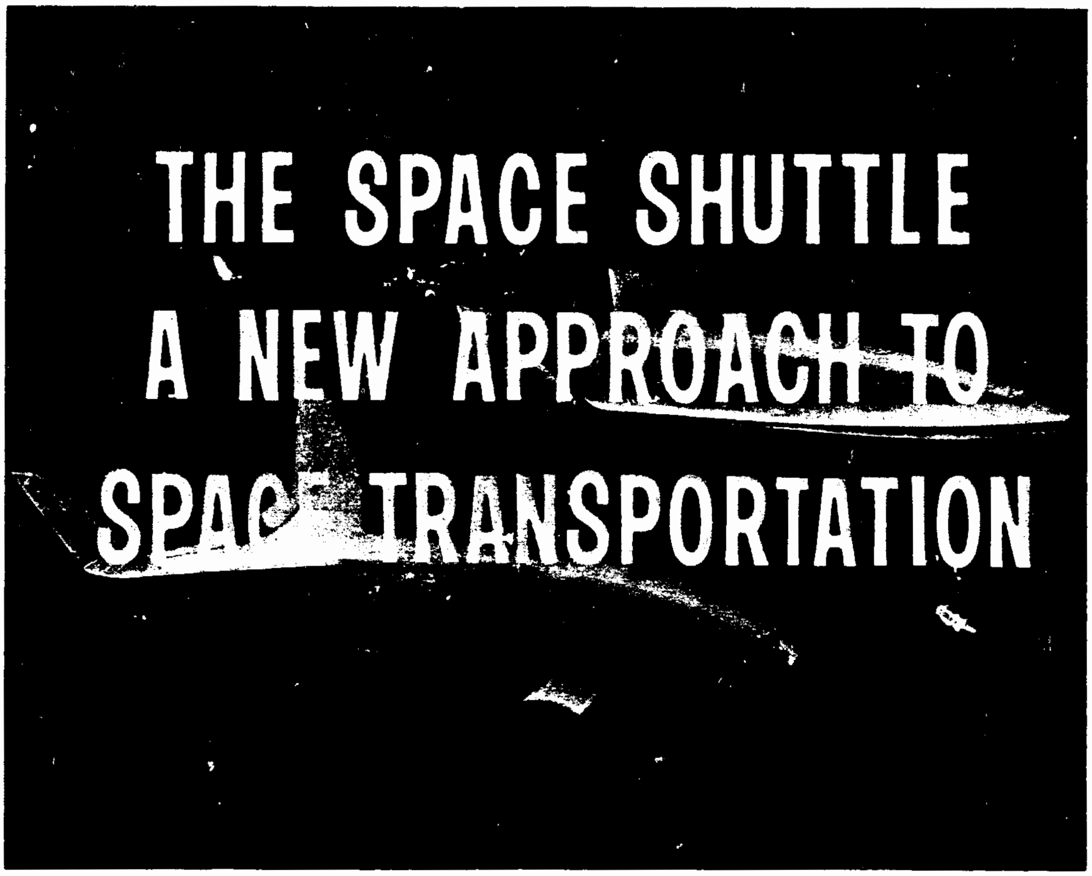

L. E. DAY

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THE SPACE SHUTTLE

A NEW APPROACH TO SPACE TRANSPORTATION

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By

L. E. Day
Manager, Space Shuttle Task Group
Office of Manned Space Flight
National Aeronautics and Space Administration
Washington, D. C. 20546

THE SPACE SHUTTLE

A NEW APPROACH TO SPACE TRANSPORTATION

INTRODUCTION

The accomplishments of the space program over the past decade have been possible through the use of highly reliable expendable launch vehicles and non-reusable spacecraft. Over the years a large family of launch vehicles has emerged to satisfy a range of missions and payloads. In looking toward the next decade to space activity where increased application will follow exploration, the United States is actively studying a reusable space vehicle - the Space Shuttle - which can meet the requirements for a wide variety of missions and payloads at a significant reduction in costs. President Nixon referred to the space shuttle in his March 7, 1970 Space Message when he noted, "Our present rocket technology will provide a reliable launch capability for some time. But as we build for the longer-range future, we must devise less costly and less complicated ways of transporting payloads into space.... We are currently examining in greater detail the feasibility of reusable space shuttles as one way of achieving this objective."

PROGRAM OBJECTIVES

The plans for the reusable space shuttle are directed at achieving (Figure 1):

a. A significant reduction, perhaps an order of magnitude, in cost of delivering men and payloads to earth orbit;

b. A less severe launch and reentry environment thereby providing an opportunity for transport of non-astronaut personnel and a reduction in the cost of payloads;

c. A flexible capability to support a broad spectrum of manned and unmanned payloads and missions which can exploit new earth orbital operations as well as support synchronous and planetary missions;

d. Broader international participation in terms of both development and operations.

FEASIBILITY OF THE CONCEPT

Studies of the feasibility of reusable space vehicles using both rocket ıd combination rocket-air breathing engines have been conducted in the United States and Europe for over a decade. Even earlier work is attributed to Professor Eugene Sänger, one of the pioneers in this field.

In the first half of the 1960's, Eurospace initiated a number of studies on the Aerospace Transporter involving industrial groups throughout the countries of Western Europe. No attempt will be made to summarize this important work but it is noted as significant background. Much of this work was reported at the United States - European Conference on "Low Cost Space Transportation" held in California in May 1967. Notable at that meeting were results of studies done by Dassault (Reference 1), Junkers (Reference 2), British Aircraft Corporation (Reference 3), Hawker Siddeley (Reference 4), and Nord-Erno (Reference 5). At that same meeting a number of papers presented work accomplished in the United States (References 6, 7, 8 and 9).

In addition to the various studies mentioned, there has been a considerable background of experience generated from the United States programs employing the X-15 research airplane and the lifting body flight programs of the HL-10, X-24 and M2. Adding to this experience are the development and operational manned space flight programs of Mercury, Gemini and Apollo. Of course, the development of supersonic military and transport aircraft, both in the United States and Europe, have also provided valuable experience (Figure 2).

The practicality of a two-stage space shuttle type vehicle is dependent on achieving very high efficiencies in propulsion and the structural/thermal protection systems. For the rocket propelled vehicle a high specific impulse (Isp) of 450 to 460 seconds is required for the two-stage vehicle if the lift-off weight and size of the vehicle are to be manageable. Extensive development and operational experience on large liquid hydrogen/liquid oxygen rocket engines has been obtained in the Saturn launch vehicle of the Apollo program. This experience together with ten years of technology and advanced development programs on high pressure hydrogen/oxygen rocket engines now gives us the confidence that the required high specific impulse can be developed on our flight engines.

Although the achievement of efficient cryogenic stages for the Saturn V vehicle was a significant structural development, we cannot minimize the additional work to be done in designing and developing an integrated structural/thermal protection system for a reusable space vehicle.

This background served as a basis for a series of feasibility studies (Phase A) during 1969 focused on the space shuttle concept. The results of those studies were presented at the Space Shuttle Conference in Washington in October, 1969 together with the results of a number of European studies (Reference 10). Based on these studies and additional work done within NASA, we are convinced of both the technical feasibility and the economic benefits of the space shuttle. Therefore, we have initiated a definition program including the preliminary design of the space shuttle vehicle and the main rocket engine and a supporting technology program.

SYSTEM CHARACTERISTICS OF THE SPACE SHUTTLE

Our studies indicate the space shuttle vehicle should have the characteristics shown in Figure 3. It should be a fully reusable two-stage vertical take-off and horizontal landing space vehicle capable of transporting 25,000 pounds ($\approx$ 11,350 kilograms) to the design reference orbit of 270 n.m. at 55^{o} orbital inclination. The space shuttle must have a large internal cargo bay which will give it the capability of carrying a variety of manned and unmanned payloads to low earth orbit. The large internal payload compartment will allow the shuttle to deliver to low earth orbit both a satellite and a high energy stage for a synchronous orbit or a planetary mission.

We expect the gross lift-off weight of the shuttle to be approximately 1.6 million kilograms fully fueled and with the payload on-board. As in the case of most launch systems, one of the most critical sub-systems will be the rocket engines. For both the booster and the orbiter we will use high pressure hydrogen/oxygen rocket engines which can be throttled to keep the acceleration during ascent to less than 3 g's. Both the orbiter and booster are planned to have a 2-man crew. Our present plan is to provide shirt sleeve environment for the crew and passengers in both vehicles. The number of 12 passengers has been selected to provide the appropriate crew replacement for space station logistic missions as well as carry out manned missions with the shuttle.

Shown in Figures 4 and 5 are two representative configurations now being studied. Both concepts are similar in terms of size, performance and on-orbit operational modes. The fundamental difference between the two concepts is in the design of the orbiter. The first concept (Figure 4) has straight wings and is designed for reentry at a high angle of attack. This mode of reentry results in a significant deceleration at higher altitudes and thereby shortens the duration of the heat pulse. The reduced heat pulse places less demands on the thermal protection system and is an important consideration. On the other hand, the reentry at high angle of attack provides a lower lift to drag ratio at hypersonic speeds and hence a smaller manuevering capability. The second concept shown in Figure 5 is a delta configuration. This configuration may reenter the atmosphere at lower angles of attack and achieve a higher hypersonic lift to drag ratio and accordingly a higher cross-range than the fixed wing concept. However, the delta configuration reentering at the low angle of attack will experience a more severe thermal environment which complicates the thermal protection system. There will be other differences between these two concepts such as differences in payload capability and subsonic flight and landing characteristics which must be thoroughly understood before a choice can be made. These studies are representative of those in progress to understand the advantages and disadvantages of the different configurations.

For either configuration staging of the two vehicles occurs at approximately 60 kilometers altitude and a speed of approximately 3000 meters per second. The booster then descends at a high angle of attack to minimize the heat pulse and when it reaches subsonic speed the jet engines are started for the 600 kilometer cruise back to the launch site. The orbiter continues on to orbit to complete the mission. Time on-orbit will vary according to the mission, but the orbiter will have a nominal seven day mission capability.

The size, weight and other characteristics of the shuttle are compared to current flight systems in Figure 6. The landing speed of the booster of 140 to 155 knots will be comparable to the 747 transport airplane.

Orbiter landing speed will be in the range of 150 to 170 knots comparable to the supersonic transport. Dry weights of the orbiter and the Concorde are comparable. The booster dry weight is about 35,000 kilograms more than the empty weight of the 747.

The primary operational characteristics we are striving to achieve are shown in Figure 7. We expect to achieve low operational costs by approaching an airline type operation in terms of ground, preflight checkout and a two week turn-around between flights. By intact abort we mean safe recovery of crew, vehicle and payload in event of an emergency. As mentioned earlier, we will maintain less that 3 g's acceleration both for ascent and reentry. We expect the vehicle to have a reusable life of at least 100 missions with minimal refurbishment. Of course, on initial vehicles a lesser number of flights will be acceptable. Those areas which may limit the numbers of flights are probably the heat protection system and perhaps the rocket engines. Vehicle systems will be designed to minimize the amount of ground checkout and flight support over what we have been accustomed to using for past expendable vehicles. The very nature of the vehicle, the fact that it will establish a history of operations by its reuse, will be very fundamental to the amount of ground checkout which must be done prior to each flight. The vehicle will have a nominal seven day mission capability with a two week turn-around between flights. Because no tanks or hardware are dropped the shuttle can be safely launched into any orbit without concern about its trajectory passing over populated areas. This will give it an all azimuth launch capability and provide an operational flexibility not achievable with present day launch vehicles.

MISSION CAPABILITIES

The space shuttle can carry out four basic types of mission by operating as:

1) reusable launch vehicle
2) a logistic vehicle for a space station
3) an orbital experiments vehicle
4) a special purpose space vehicle

Reusable Launch Vehicle

As a reusable launch vehicle it is envisioned that the space shuttle eventually will replace essentially all the present day launch vehicles or their derivatives except for very small vehicles of the Scout class and the Saturn V. This will be possible because the low cost per flight of the reusable vehicle, \$4-5 million, including amortization, will make it competitive even if it carries only a portion of its full payload capability on particular missions. Shown in Figure 8 are the cost of transporting payloads to orbit for a range of launch vehicles. For its maximum payload to low earth orbit the shuttle will approach $250 to $200 per kilogram which is nearly an order of magnitude less than present day expendable vehicles. Figure 9 shows the payload capability for a range of orbit inclinations and altitudes.

For large payloads on the order of 50,000 kilograms or more, we are studying the possibility of using an expendable stage in conjunction with the reusable shuttle booster. (See Figure 10.) Preliminary indications are that this combination provides a very powerful capability for placing large payloads into low earth orbits. Of course, this would only provide one way transportation and any return capability would have to be accommodated by returning smaller modules of the payload on subsequent flights of the orbiter. The use of existing stages such as the Saturn 3rd stage (SIVB) as well as optimum stages is being studied for an expendable stage on the reusable booster.

In addition to the low launch cost we expect the less severe acoustic and acceleration environment of the shuttle payload compartment to allow significant reductions in the cost of payloads. The major differences in payload environment expected for the shuttle compared to present day launch vehicles are summarized in Figure 11. The payload design will be further aided by allowing greater volume and weight for many payloads because of the shuttle cargo bay accommodations. Preliminary analyses indicate a reduction of payload development costs of 25-30% may be expected for payloads designed for the shuttle compartment as opposed to expendable vehicles. In addition to the payload being protected from the boost environment of acceleration, vibration, and acoustics there will not be the shocks associated with explosive devices typically used on shrouds and the separation of payloads. Furthermore, on-orbit checkout of the payload can be accomplished before it is committed to its mission, thereby saving those missions where the payload was satisfactorily checked out on the ground but failed in some way, perhaps in the deployment of solar panels or antenna, once the payload was delivered to orbit (Figure 12). In the case of the shuttle, failed payloads would be returned to the ground for subsequent analyses and repaired thereby saving the cost of the payload. This could amount to very substantial savings in cases of payloads such as a large space telescope which cost from $80 to $100 million each.

As mentioned earlier payloads destined for high energy orbits are delivered with their propulsive stages to low earth orbit by the shuttle.

Figure 13 illustrates a typical installation of a communications satellite and its stage shown within the protected environment of the shuttle payload compartment. The increasing number of communications, weather and navigation satellites at synchronous altitude makes it important that the shuttle payload compartment be sufficiently large to accommodate the high energy stages plus the satellite. This is emphasized in Figure 14 where it can be seen that the payload compartment must be at least 15 meters long if a majority of the space traffic is to be carried by the shuttle. In addition, future space plans include a reusable orbit-to-orbit shuttle, also called a space tug, which must work in conjunction with the earth-to-orbit space shuttle. The space tug now being studied by Europeans as well as the United States would be carried internally in the payload compartment along with its payload. The combination of the space tug plus the space shuttle provide a truly low cost approach to space transportation both for low earth orbit and high energy missions (Figure 15).

Logistics Vehicle For Space Station

The shuttle will be an efficient means for providing logistic support for the space station. Its passenger capability of 12 will be adequate for crew rotation and in addition it can provide replacement experiments and supplies as needed by the station. It is estimated that a 12 man space station will require approximately 20,000 kilograms of expendable supplies and experiment equipment on a 3 month resupply cycle. Studies are now being carried out to determine the feasibility of a modular space station where the modules are of suitable size and weight for delivery to earth orbit by the space shuttle itself. Thus the assembly could consist of 4-5 modules in space suitable for housing, experimentation and space station support, as shown in Figure 16.

Orbital Experiment Vehicle

One of the most exciting possibilities for the shuttle is operation in a short duration mission or sortie mission. In this capacity the shuttle would serve as an orbital vehicle with the payload or experiments remaining integral to the shuttle. It would have the capability to carry out manned experiments from space. Such experiments could range from meteorology or earth resources to astronomy. The advantages for this type operation would be in the ability to use experimental equipment not greatly different from that we use in our scientific laboratories on the ground. Perhaps it could be the same or similar type equipment because of the protected environment of the shuttle -- thus providing substantial cost savings. The experimenters of course, could work with their own equipment as they do in an earth bound environment. Furthermore, instead of the 2-3 years lead time that space experimenters presently require, we should expect this lead time to shorten markedly thereby providing greater flexibility for carrying out experiments.

We think of the space shuttle operating in a sortie mode as being very much like the operation we are presently carrying out with our NASA Convair 990 airplane (Figure 17). It takes off about once a month with a load of experiments that can be conducted on a flight. When it returns the data is immediately available and either the same experiments are replenished with film or tape or new experiments are introduced. The 990 aircraft has been used to chase eclipses of the sun in order to extend experiment time beyond that available at one point here on earth. It has also been used for photographic missions to support our earth resources survey program. Operating in the sortie mode, the space shuttle could provide a week or more of on-orbit time in a shirt sleeve environment for short lead time experiments and quick reaction special opportunities.

Manned operation should permit simplicity, economy, and on-orbit repair. It should be able to take advantage of unexpected opportunities and will be able to return photographic and other data to earth at the end of the flight. Experimental payloads in the 990 cost several hundred dollars per kilogram. Based on that experience we would expect to drive down the present satellite costs of $45,000 to $30,000 per kilogram to perhaps $1,000 per kilogram for experimental payloads used in the sortie mode of the shuttle.

Special Purpose Space Vehicle

The fourth category of missions which the shuttle can carry out will be special purpose or dedicated missions. One example of this will be the use of the shuttle quick reaction capability for space rescue. Its ability to launch within a few hours from its standby status plus the all azimuth capability of the vehicle and the ability to carry personnel in a mild environment provide the essential capabilities for space rescue.

KEY TECHNICAL AREAS

Having discussed the general configurational concepts and the mission capabilities of the space shuttle, we can now turn to the principal technical areas which need to be explored and solved. A great deal of the technology which is needed for the space shuttle is already available.

Aerothermodynamics

One of the areas which must be pursued is the determination of the aerothermodynamic characteristics of the configurations now under consideration. This will involve a large amount of analytical work as well as wind tunnel testing for both aerodynamic and thermodynamic characteristics over the range from subsonic to hypersonic speeds. A typical tunnel test of an orbiter under hypersonic considerations is shown in Figure 18.

All of the aero and thermodynamic issues are configuration peculiar. It is estimated that 2,000 to 3,000 hours of wind tunnel time will be needed for each of the configurations during the preliminary design period.

Thermal Protection

Typical maximum surface temperatures expected on the booster and orbiter are shown in Figure 19. The heat protection materials being studied are both re-radiativ. metallic and non-metallic systems. Typical configurations of the metallic and non-metallic heat protection systems are shown in Figure 20. The metallic systems employ super-alloys such as Rene 41, TD-NiCr (thoria dispersed nickel chrome), and coated refractory metals, e.g., columbium. The non-metallic systems employ various types of harden compacted fibers (HCF) or reusable external insulation systems with a hardened surface backed up by insulation and applied to the exterior of the vehicle. While more work has been done in the metallic areas, the promises of the non-metallics are encouraging us to invest substantial money to bring technology forward. We are also examining the application of low cost ablatives for localized high heat areas such as nosecaps and portions of wing and tail leading edges.

Structures

The payload capability of the two-stage shuttle is highly dependent on the efficiency of the structure, i.e., a high propellant to structure mass structure. At the same time, we will be designing a vehicle which must be reused repeatedly. Even with these requirements, we are striving to employ straightforward structural concepts which are not prohibitively expensive to manufacture and test. The "weight validity" of any given design is always questionable until details have been established and critical design features actually built and tested. We are initiating several efforts to allow testing of critical large-scale elements of the structure at an early stage of the program.

Propulsion

As mentioned earlier, we are planning to use liquid oxygen/liquid hydrogen engines for both the orbiter and the booster engines. The same basic engine will be used in both vehicles in order to have a single engine development program. The orbiter will have a longer skirt on the engine to achieve a higher expansion ratio and a higher specific impulse. The primary characteristics of this engine are shown in Figure 21. The thrust of each engine will be approximately 182,000 kilograms. The engine must be throttleable over a 2 to 1 range and must have the accessibility and maintenance characteristics appropriate for a reusable engine. The engines being pursued for the shuttle are high-pressure stage combustion engines.

Based on our experience with hydrogen/oxygen engines, we believe that they are well suited as reusable engines and that we can achieve the required specific impulse. Repeated ground firings of hydrogen/oxygen engines, such as the RL-10 and the J-2, show them to be in almost new condition after burns equivalent to 50 or 60 flights. Therefore, we believe the goal of a hundred reuses with minimum maintenance to be realistic.

The definition and preliminary design of the main engine for the shuttle are based on our Saturn experience and nearly a decade of technology in high pressure engines. Over the past 10 years approximately $100 Million has been invested in the technology associated with these high performance engines. As a matter of interest, there has also been work going on in Europe in high pressure engines. The design of a high pressure liquid oxygen/liquid hydrogen engine is now being studied here in Europe for the Europa III.

The attitude control propulsion system for the shuttle will also use hydrogen/oxygen propellants. Considerable work must be done in this area because the use of gaseous hydrogen/oxygen poses new problems in ignition and overall system design.

<u>Air Breathers</u>

Our present studies of the Space Shuttle are examining the use of air breathers on both the orbiter and booster employing either hydrogen or JP fuel. The airbreathing engines on the booster are required for its 600-kilometer cruise back to the landing site and landing. We are examining whether the booster need fly all the way back to its initial launch site or to some down range location. Trade-offs between vehicle size and operational constraints must be studied. In the case of the orbiter, the principal issue is whether or not to have airbreathers to provide power landing and go-around capability. Substantial payload gain will result if the decision can be made to omit the air breather from the orbiter. We are presently carrying out the design of the orbiter with the location of the jet engines such that they can be removed at a later date without a major impact to the vehicle. This option would give us the capability of performing initial flights with jet engines in the orbiter until operational experience had been gained and then to remove them and gain an increase in payload of at least 30 to 40%.

ECONOMIC CONSIDERATIONS

We have already discussed the cost savings in transportation to orbit and through simpler design, development and reuse of payloads. In order to view the expected overall saving the Space Shuttle has been compared to the present mode of space operations using today's payload and launch vehicle costs. Based on the level of U.S. space operations roughly equivalent to what we are flying today, the Space Shuttle is compared with conventional expendable systems in Figure 22. The development costs for the shuttle are shown up to the beginning of flight operations. From this point on, the launch costs of $4.5 Million per flight plus the cost of payloads add to the total cost.

The conventional system is compared with the shuttle to do the same mission during the operational period of the shuttle. The reduced costs for payloads for the shuttle, already reviewed, are a significant factor in the differences shown in Figure 22. Examination of the figure indicates that even with the large development cost of the shuttle it breaks even with conventional systems after only a few years of operation. This particular comparison for an average of 55 flights per year over a ten year period is a very conservative assumption. For a more ambitious flight program which you might expect the shuttle to stimulate, the cost comparison is even more dramatic. In our continuing economic studies, the shuttle shows cost savings over conventional systems for a wide range of development and operational cost assumptions.

PROGRAM PLANS

Schedule

The eleven months definition and preliminary design studies are scheduled to be completed by June 1971. They will provide data which will define the program in terms of vehicle design, the cost and schedule of such a program and identify critical technology requirements. At the same time we are carrying out a substantial technology program to support the needs of the pace shuttle program.

Shown in Figure 23 is a space shuttle planning schedule which indicates that design and development could be initiated in late 1971 after the completion of the present definition studies. That would allow horizontal flight tests to begin by 1975 leading to vertical sub-orbital flights by 1976. Orbital flights would follow in 1977 providing an initial operational capability. Full operational capability would be attained a year or two later.

International Participation

As mentioned earlier, the plans for the space shuttle envision opportunities for a broad international participation. The concept of the shuttle vehicle and its operations are intended to provide mission capability for a wide range of users. Furthermore, a number of steps are being taken to encourage international participation during the planning and development phase. To this end, international conferences have been held in Washington, Paris, and Bonn over the past year where NASA has reviewed and discussed plans for the post-Apollo programs. Periodic reviews of our technology programs are attended by European representatives. In all of these conferences, NASA has stressed the need for the European countries to determine what role they would propose to play. There are now encouraging signs that several European countries are making specific plans for working with us on the space shuttle. For example, arrangements are now underway between our Phase B study contractors and a number of European firms for their involvement in our Phase B studies. We believe that if these initial efforts are pursued we can look toward a period of much broader participation in space than we have previously seen.

CONCLUDING REMARKS

The challenge of the 1970's is to expand the practical applications of space technology to improve our living here on earth. The space shuttle can directly contribute to that goal by providing a versatile low cost space transportation system which promises to revolutionize the present mode of space operations. However, the development of the shuttle represents a substantial technical and managerial challenge which will require innovative approaches.

Further, we see the program offering opportunities for broad international participation which can have benefits beyond the confines of the space program. As President Nixon stated this year, "Our progress will be faster and our accomplishments will be greater if nations will join together in this effort, both in contributing the resources and in enjoying the benefits."

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PROGRAM OBJECTIVES

- REDUCE COST OF DELIVERY TO SPACE
- REDUCE PAYLOAD COSTS
- SUPPORT BROAD RANGE OF MISSIONS
- INCREASE INTERNATIONAL PARTICIPATION

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FIGURE 1

SPACE AND AERONAUTICS BACKGROUND FOR THE SHUTTLE

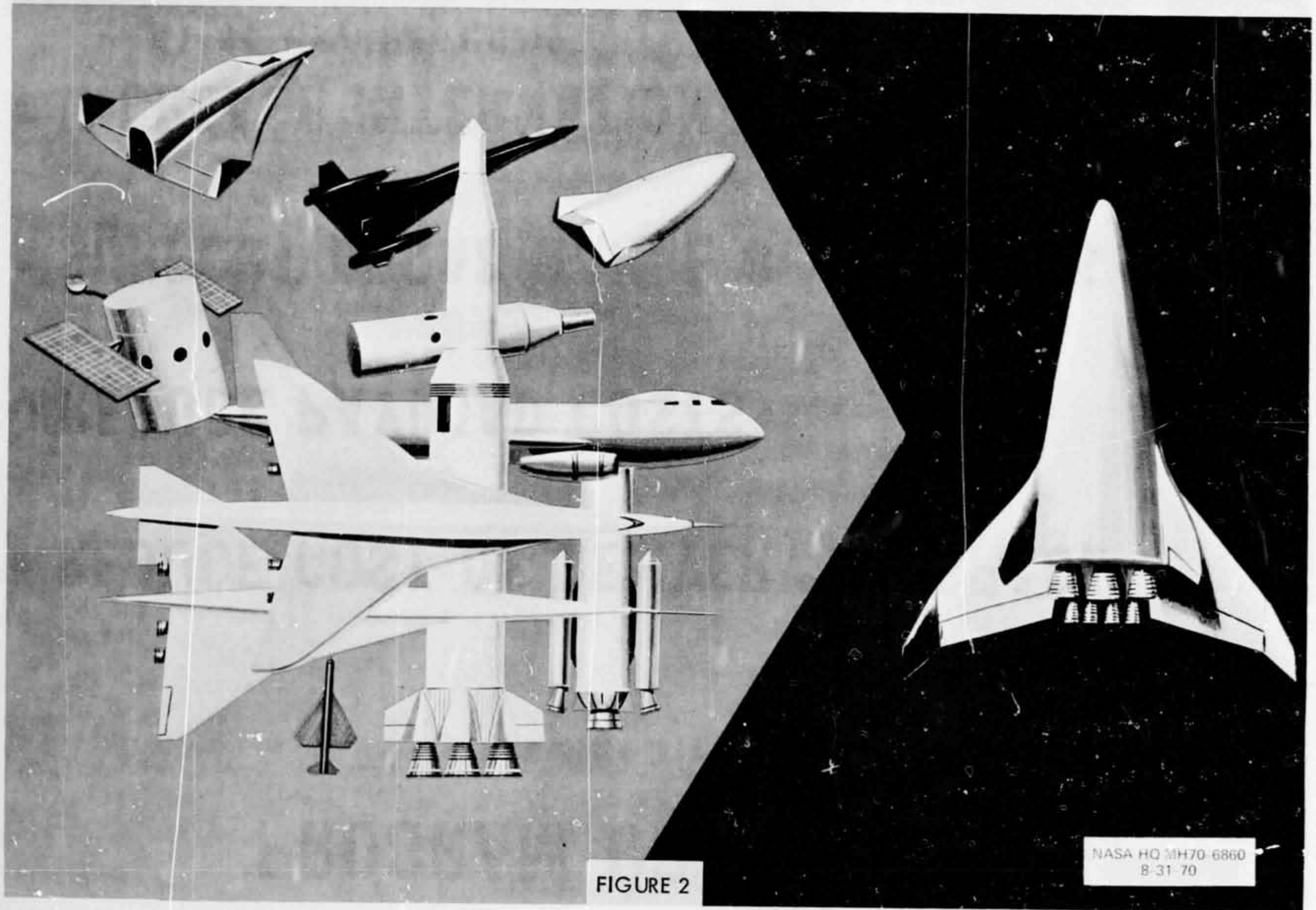
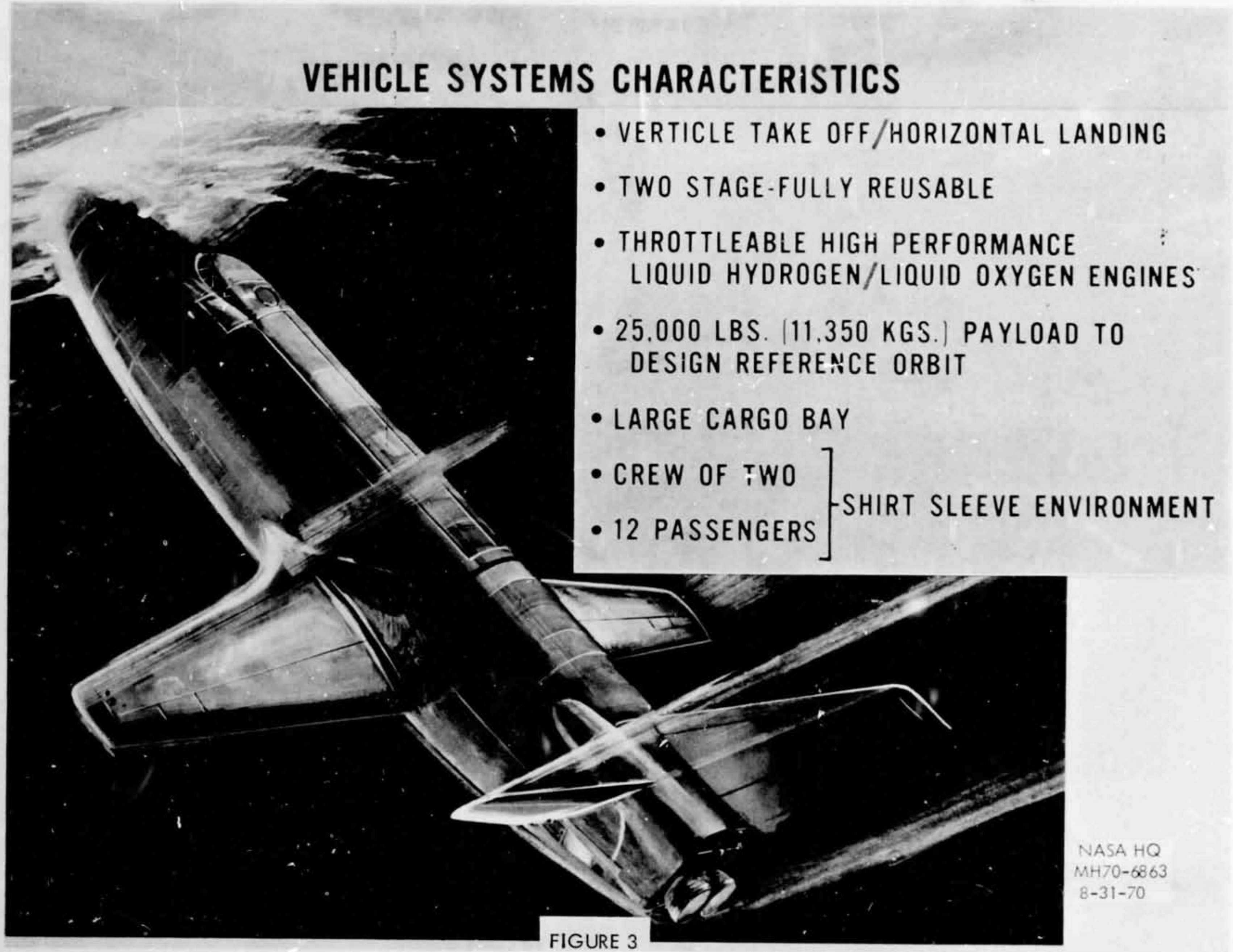


FIGURE 2


VEHICLE SYSTEMS CHARACTERISTICS
• VERTICLE TAKE OFF/HORIZONTAL LANDING
• TWO STAGE-FULLY REUSABLE
• THROTTLEABLE HIGH PERFORMANCE LIQUID HYDROGEN/LIQUID OXYGEN ENGINES
• 25,000 LBS. (11,350 KGS.) PAYLOAD TO DESIGN REFERENCE ORBIT
• LARGE CARGO BAY
• CREW OF TWO
• 12 PASSENGERS
SHIRT SLEEVE ENVIRONMENT
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8-31-70

FIGURE 3

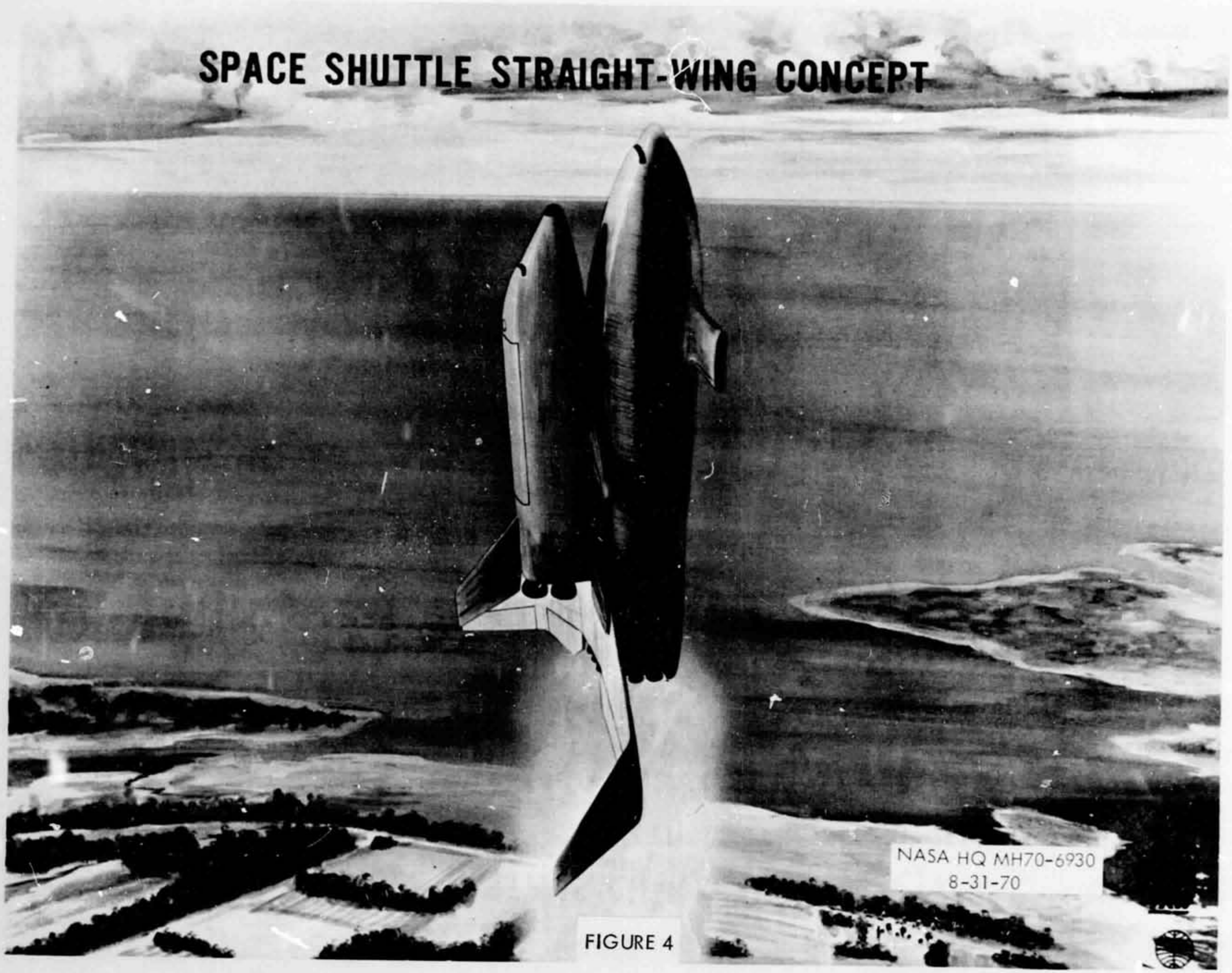
SPACE SHUTTLE STRAIGHT-WING CONCEPT
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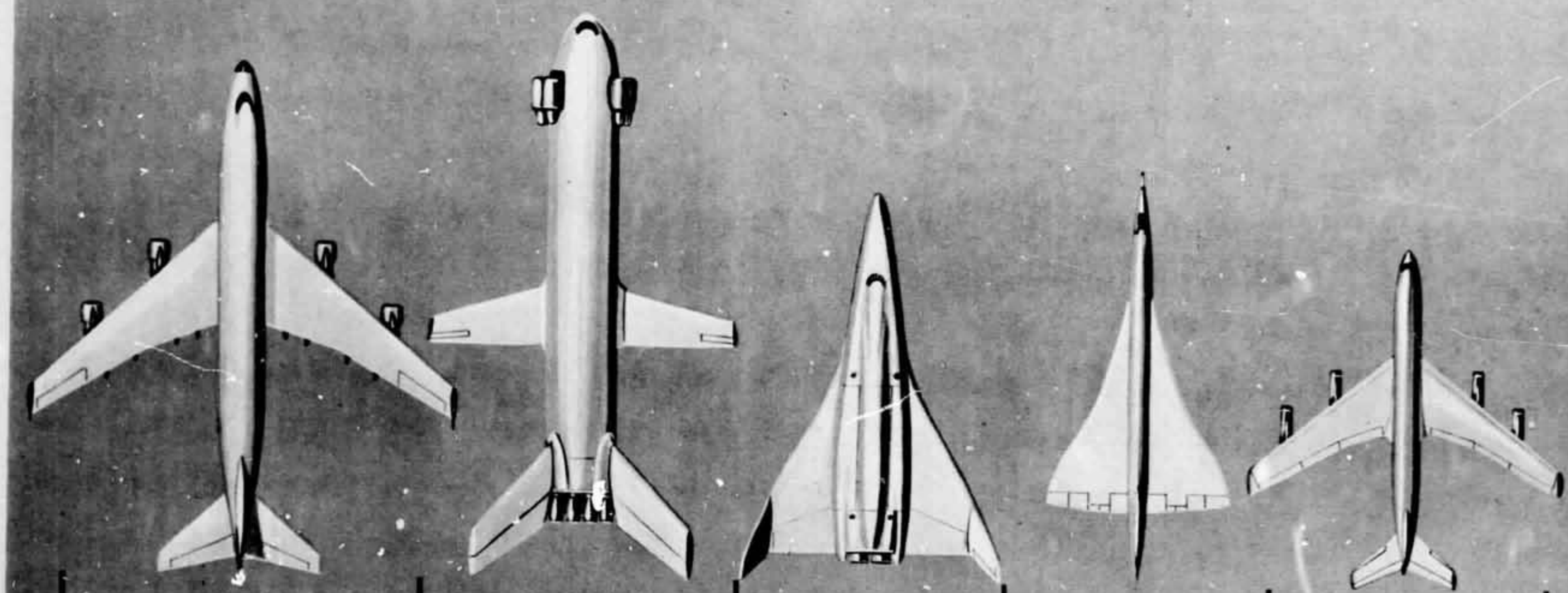
FIGURE 4

FIGURE 5

SHUTTLE COMPARISON WITH EXISTING FLIGHT VEHICLES



BOEING 747	BOOSTER	ORBITER	CONCORDE	BOEING 707
WINGSPAN 196 FT. (59.6 M.)	WINGSPAN 142 FT. (43.3 M.)	WINGSPAN 122 FT. (37.2 M.)	WINGSPAN 84 FT. (25.6 M.)	WINGSPAN 142 FT. (43.4 M.)
LENGTH 231 FT. (70.5 M.)	LENGTH 257 FT. (78.4 M.)	LENGTH 190 FT. (57.8 M.)	LENGTH 193 FT. (58.6 M.)	LENGTH 153 FT. (46.6 M.)
OPER. WT. EMPTY 365, 800 LBS. (165, 920 KG)	OPER. WT. EMPTY 444, 000 LBS. (201, 900 KG)	OPER. WT. EMPTY 195, 000 LBS. (88, 710 KG)	OPER. WT. EMPTY 190, 000 LBS. (86, 300 KG)	OPER. WT. EMPTY 135, 000 LBS. (61, 236 KG)
LANDING SPEED 140 KNOTS	LANDING SPEED 155 KNOTS	LANDING SPEED 149 KNOTS	LANDING SPEED 160 KNOTS	LANDING SPEED 140 KNOTS

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FIGURE 6

OPERATIONAL SYSTEM CHARACTERISTICS

- LOW OPERATIONAL COSTS
- INTACT ABORT
- ACCEPTABLE G LOADS FOR PASSENGERS
- TWO WEEK TURN-AROUND
- 100 FLIGHT CAPABILITY
- MINIMAL REFURBISHMENT
- VEHICLE AUTONOMY (ALLOW MINIMUM GROUND CHECKOUT AND FLIGHT SUPPORT)
- NOMINAL 7 DAY MISSION CAPABILITY
- ALL AZIMUTH LAUNCH

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8 31 70

FIGURE 7

SPACE SHUTTLE OFF-LOADED COST TRENDS

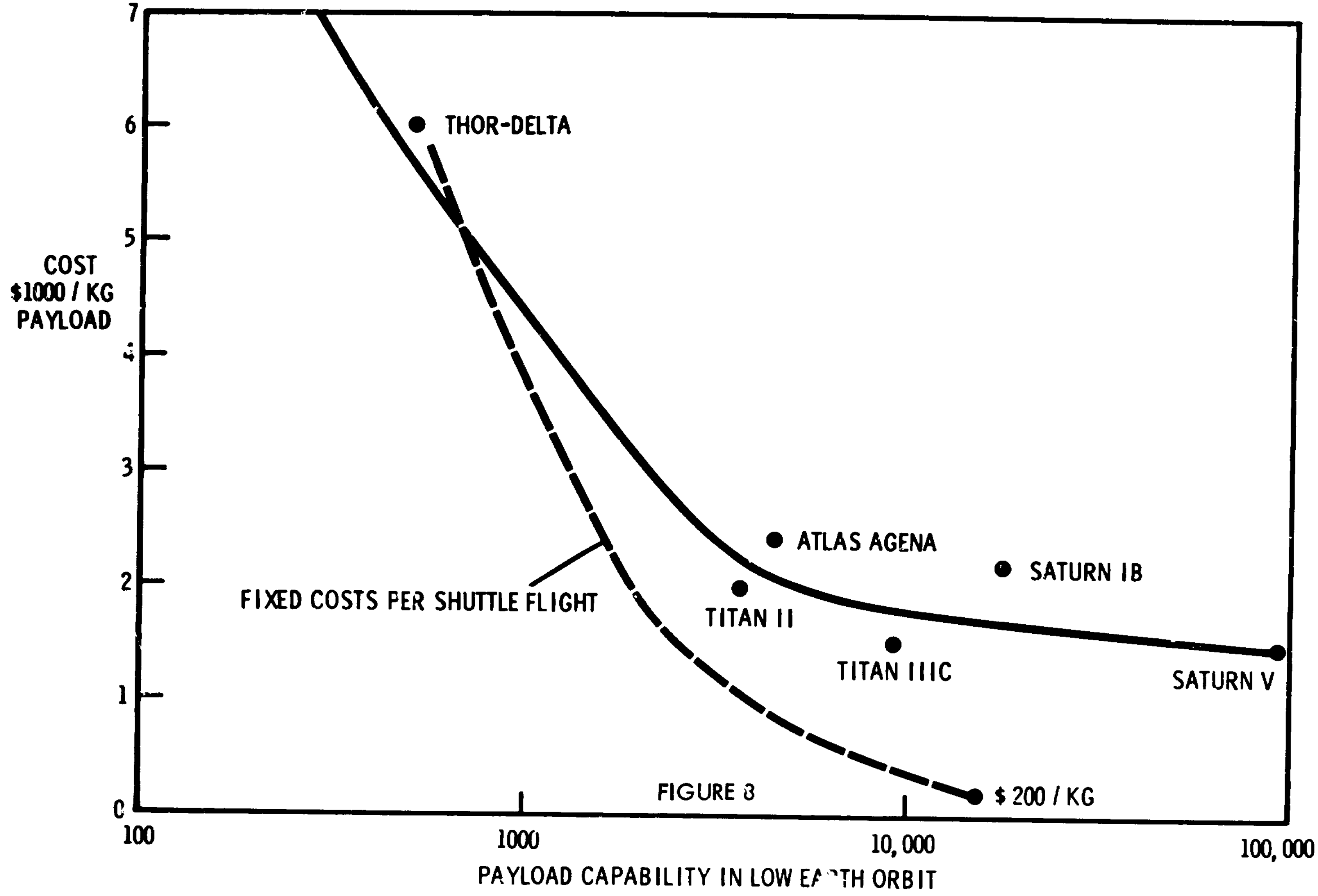

FIGURE 3

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PAYLOAD CAPABILITY
25,000 LBS. (11,350 KGS) SPACE SHUTTLE

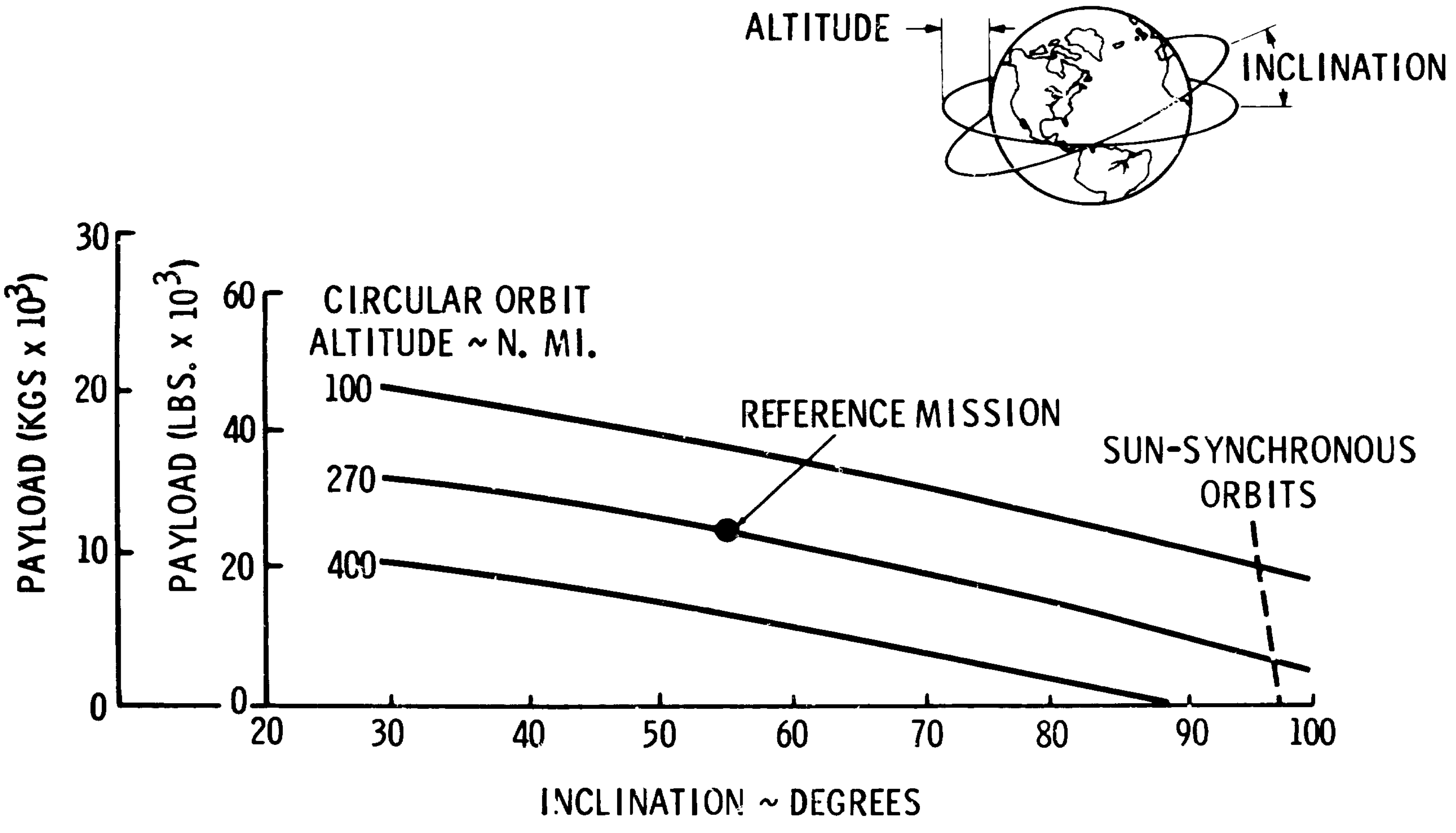

FIGURE 9

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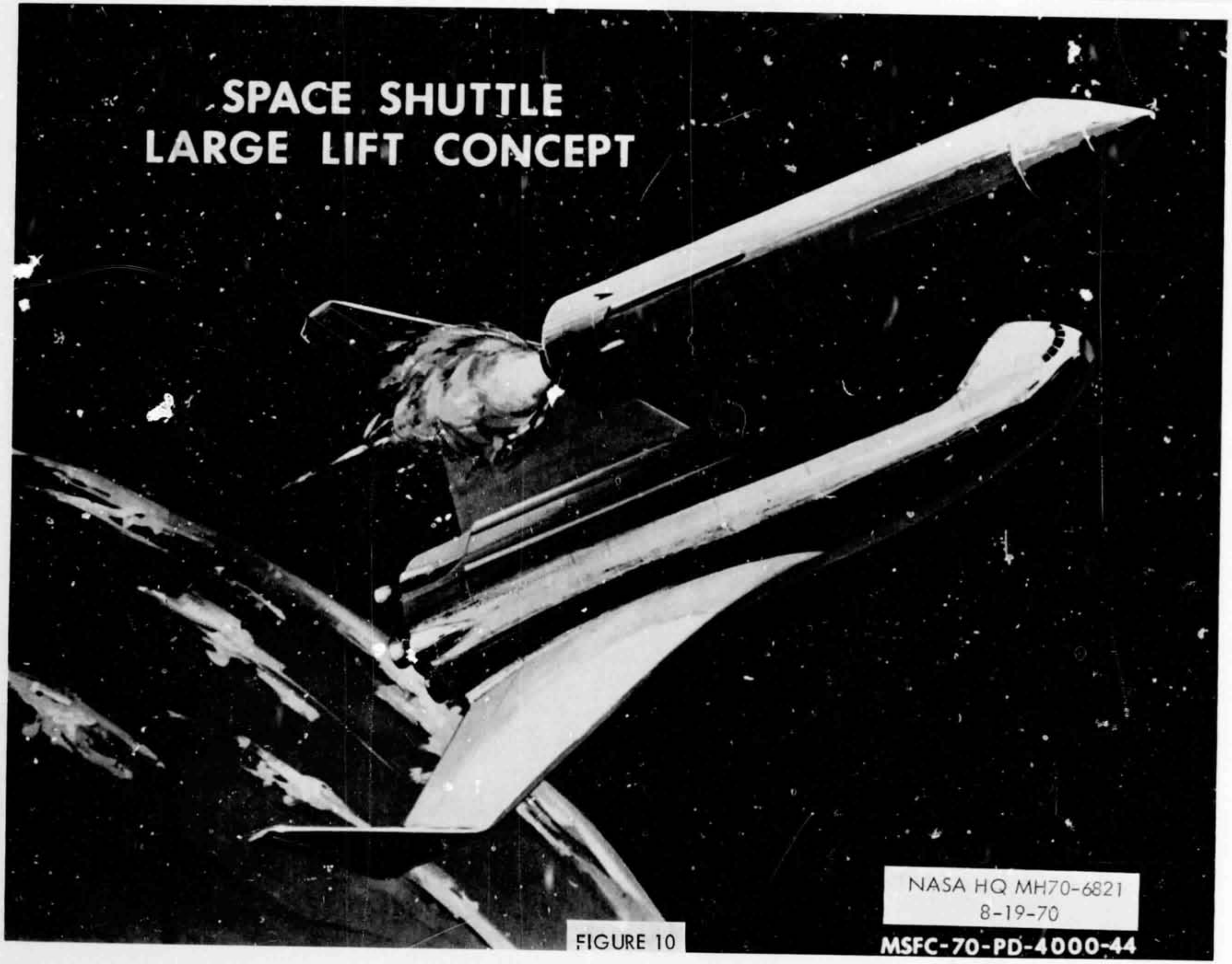

SPACE SHUTTLE
LARGE LIFT CONCEPT
NASA HQ MH70-6821
8-19-70
MSFC-70-PD-4000-44
FIGURE 10

POTENTIAL PAYLOAD SAVINGS

DESIGN FACTORS		
	CURRENT	SHUTTLE
BOOST ACCELERATION	10g	3g
SIZE	15.2 x 3.0M DIA.	18.2 x 4.6M DIA.
NOISE	180 db	PROTECTED
PYRO DEVICES	MANY	NONE
CHECKOUT	GROUND	IN ORBIT
RELIABILITY	93%	INTACT ABORT
RETURN AND REPAIR	NO	YES

FIGURE 11

NASA HQ MH70-6867
8-31-70

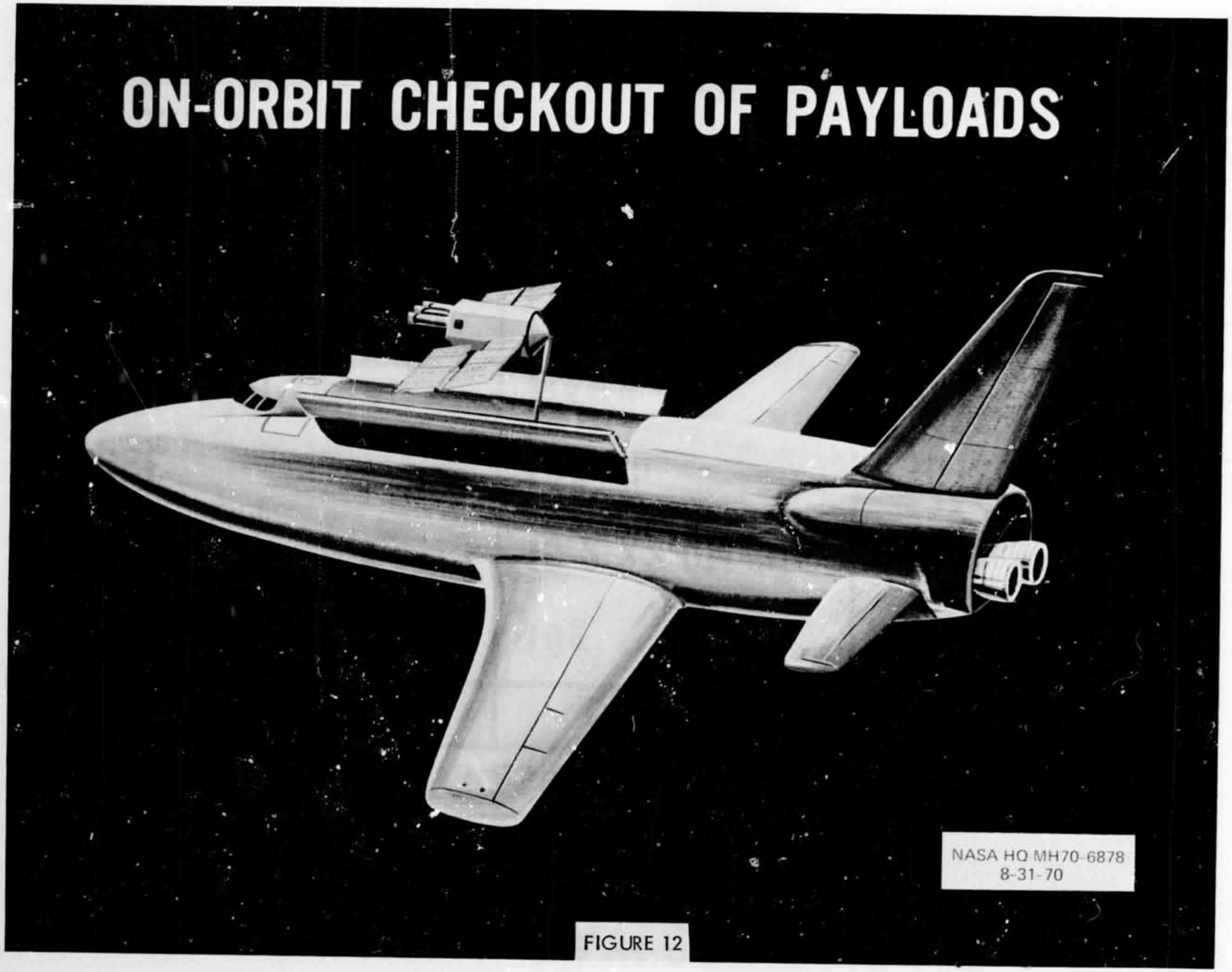
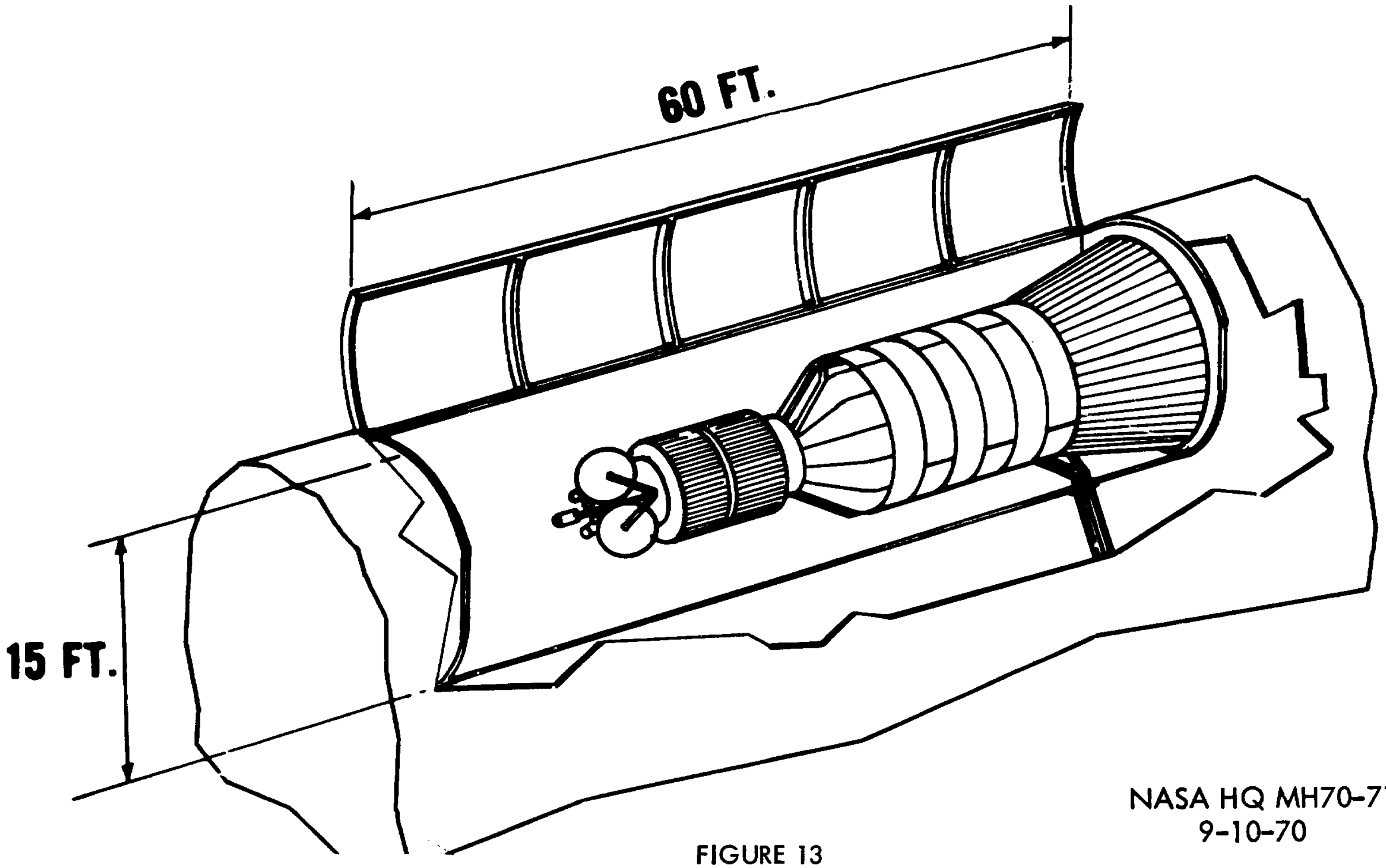


FIGURE 12

COMMUNICATIONS SATELLITE IN SHUTTLE PAYLOAD COMPARTMENT



NASA HQ MH70-7100
9-10-70

FIGURE 13

MISSION UTILIZATION AS A FUNCTION OF CARGO BAY DIMENSIONS

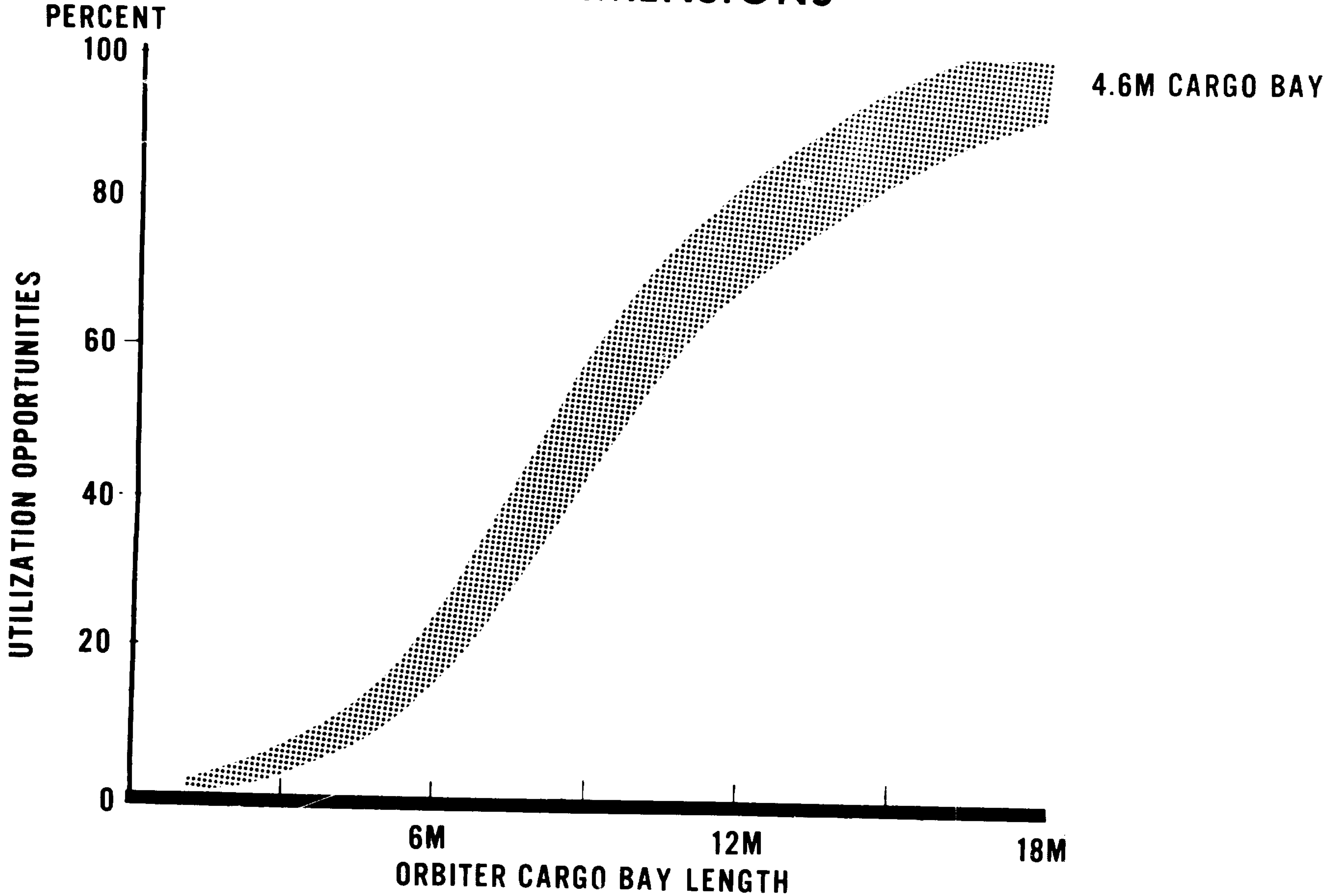


FIGURE 14

NASA HQ MH70-6396

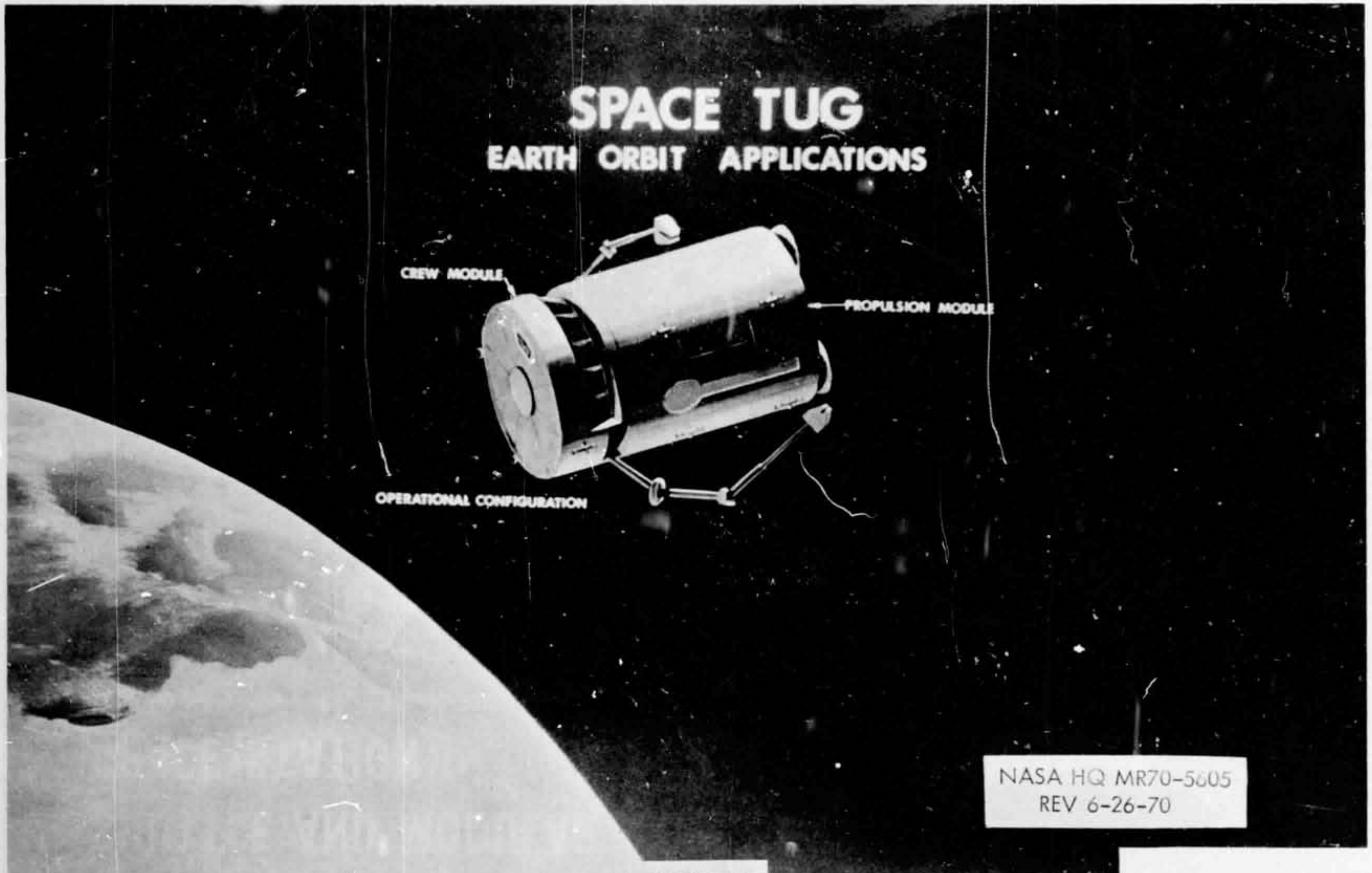

SPACE TUG
EARTH ORBIT APPLICATIONS
CREW MODULE
PROPULSION MODULE
OPERATIONAL CONFIGURATION
NASA HQ MR70-5805
REV 6-26-70

FIGURE 15

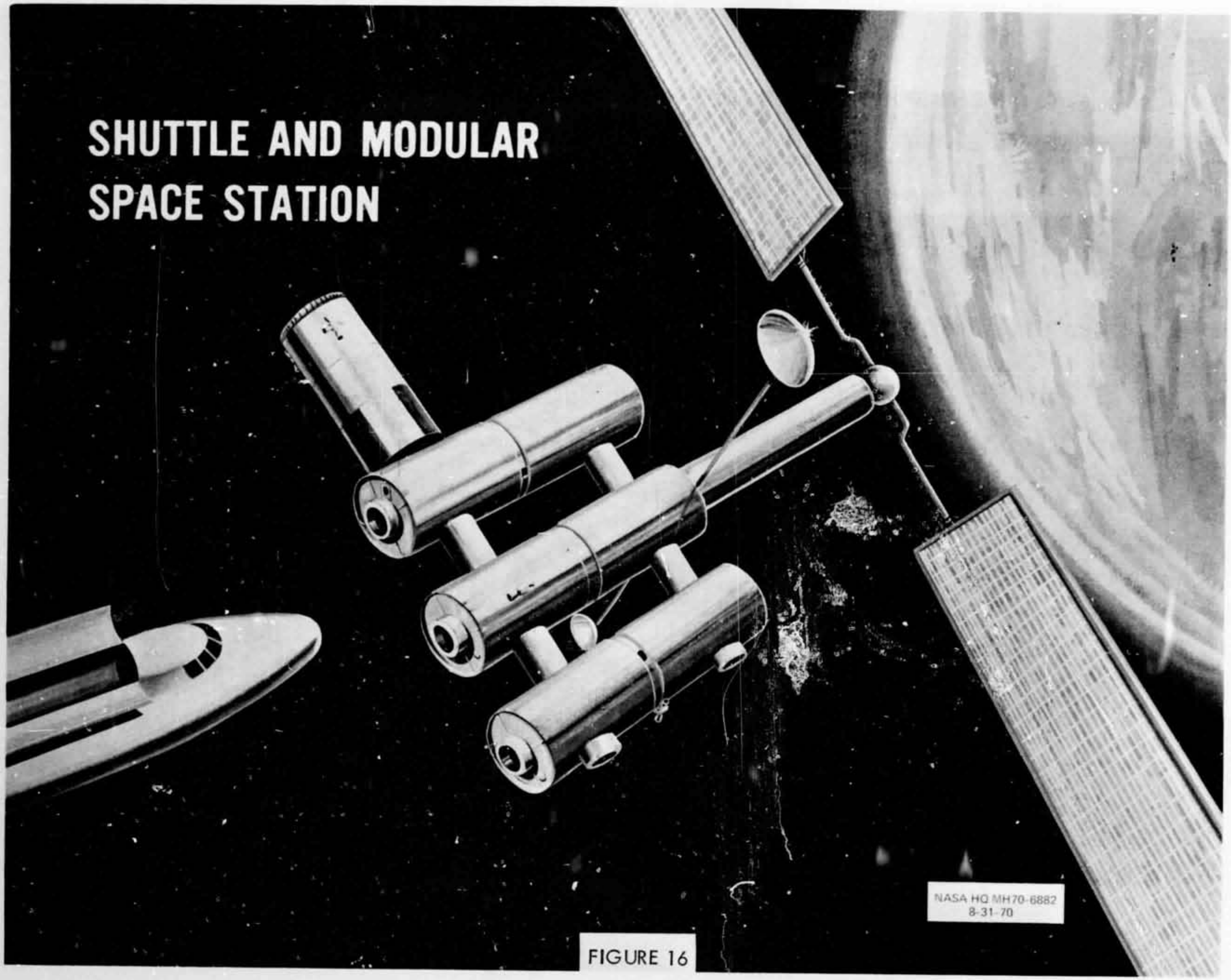


FIGURE 16

HIGH ALTITUDE EXPERIMENTS IN NASA 990 AIRCRAFT

FIGURE 17

NASA HQ MC70-6879
9-4-70

FIGURE 18

NASA HQ MH70-6883
8-31-70

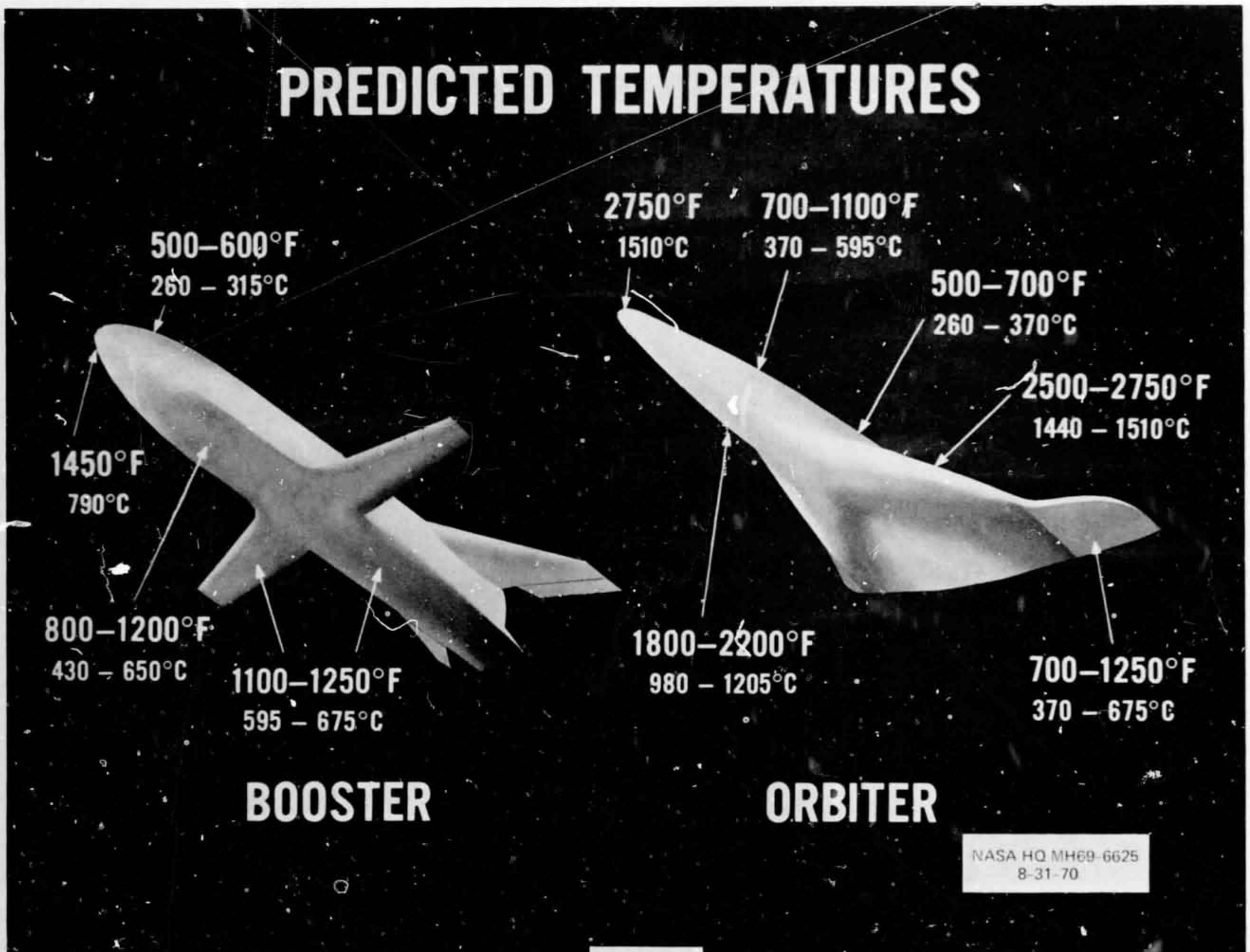

PREDICTED TEMPERATURES
500–600°F
260 – 315°C
1450°F
790°C
800–1200°F
430 – 650°C
1100–1250°F
595 – 675°C
2750°F
1510°C
700–1100°F
370 – 595°C
500–700°F
260 – 370°C
2500–2750°F
1440 – 1510°C
1800–2200°F
980 – 1205°C
700–1250°F
370 – 675°C
BOOSTER
ORBITER
NASA HQ MH69-6625
8-31-70

FIGURE 19

TYPICAL HEAT SHIELD APPROACHES

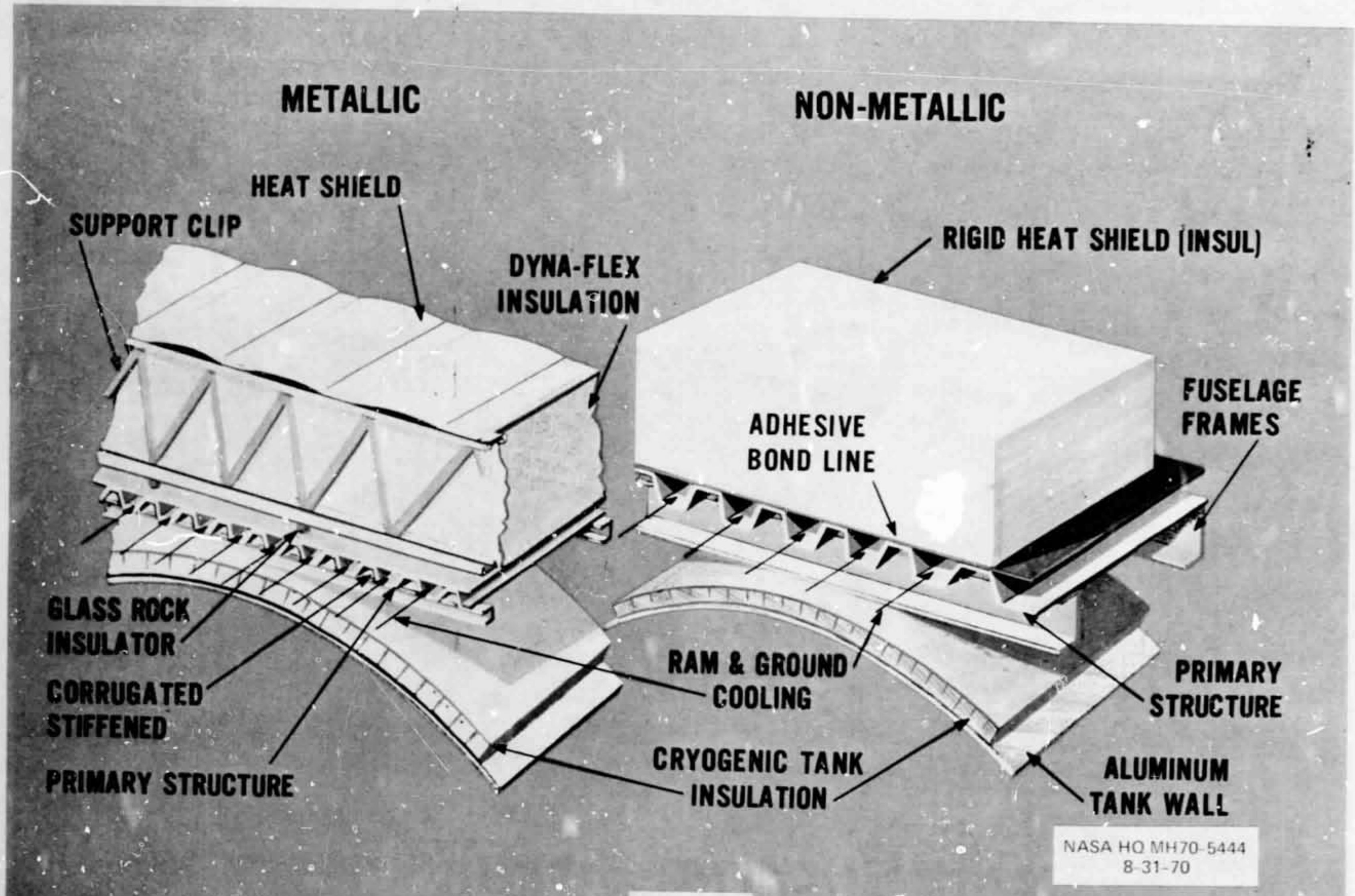
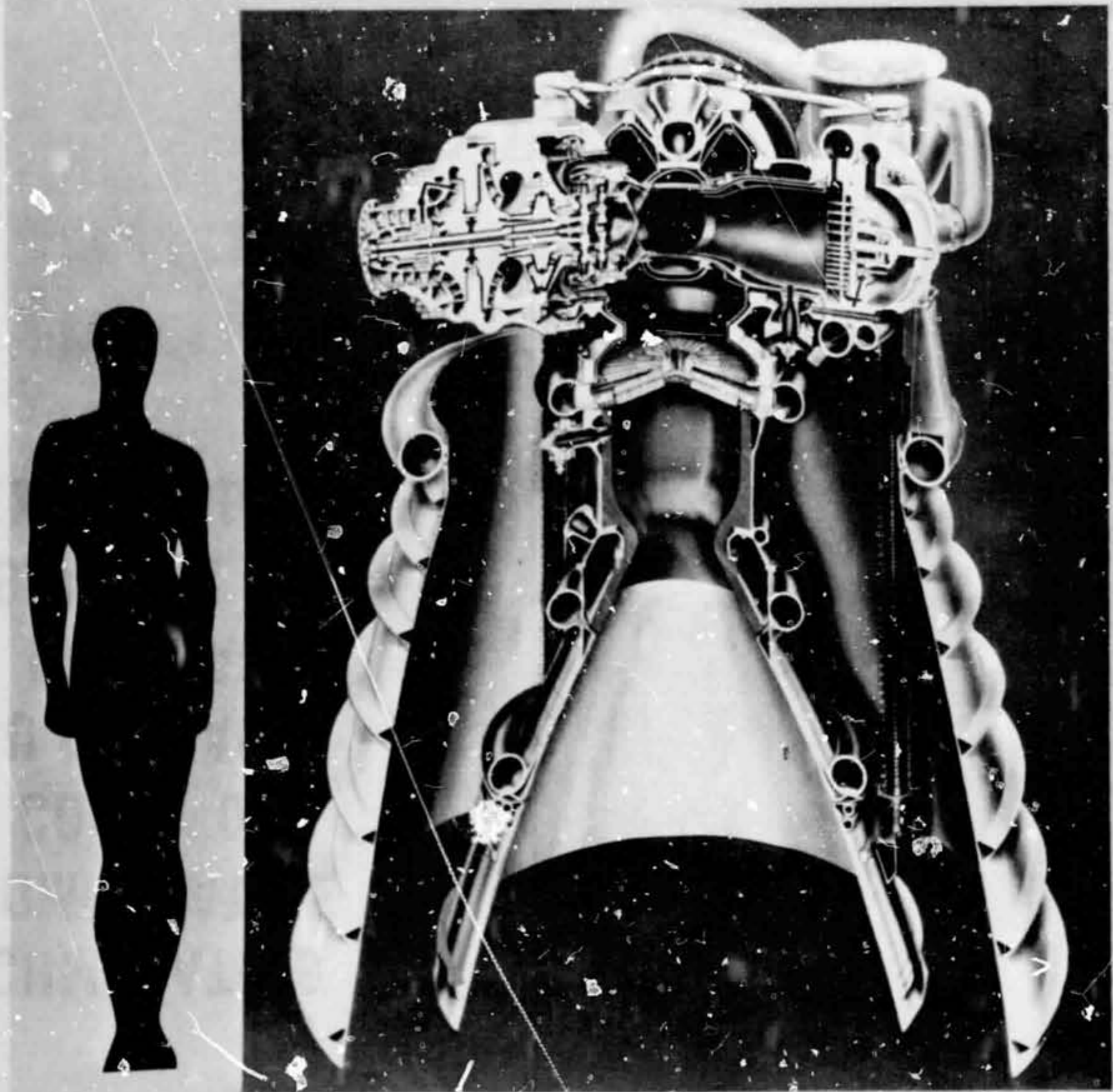


FIGURE 20

SPACE SHUTTLE MAIN ENGINE CHARACTERISTICS



- LIQUID HYDROGEN/ LIQUID OXYGEN
- 400,000 LBS. (182,000 KGS) THRUST LEVEL
- BELL NOZZLE
- HIGH PERFORMANCE
- REUSABILITY
- LOW COST OPERATION
- LONG SERVICE LIFE
- THROTTLEABLE
- MINIMUM MAINTENANCE

NASA HQ MH70-6864
8-31-70

FIGURE 21

CUMULATIVE COMPARATIVE COSTS OF U.S. SPACE PROGRAM SHUTTLE vs EXPENDABLE *

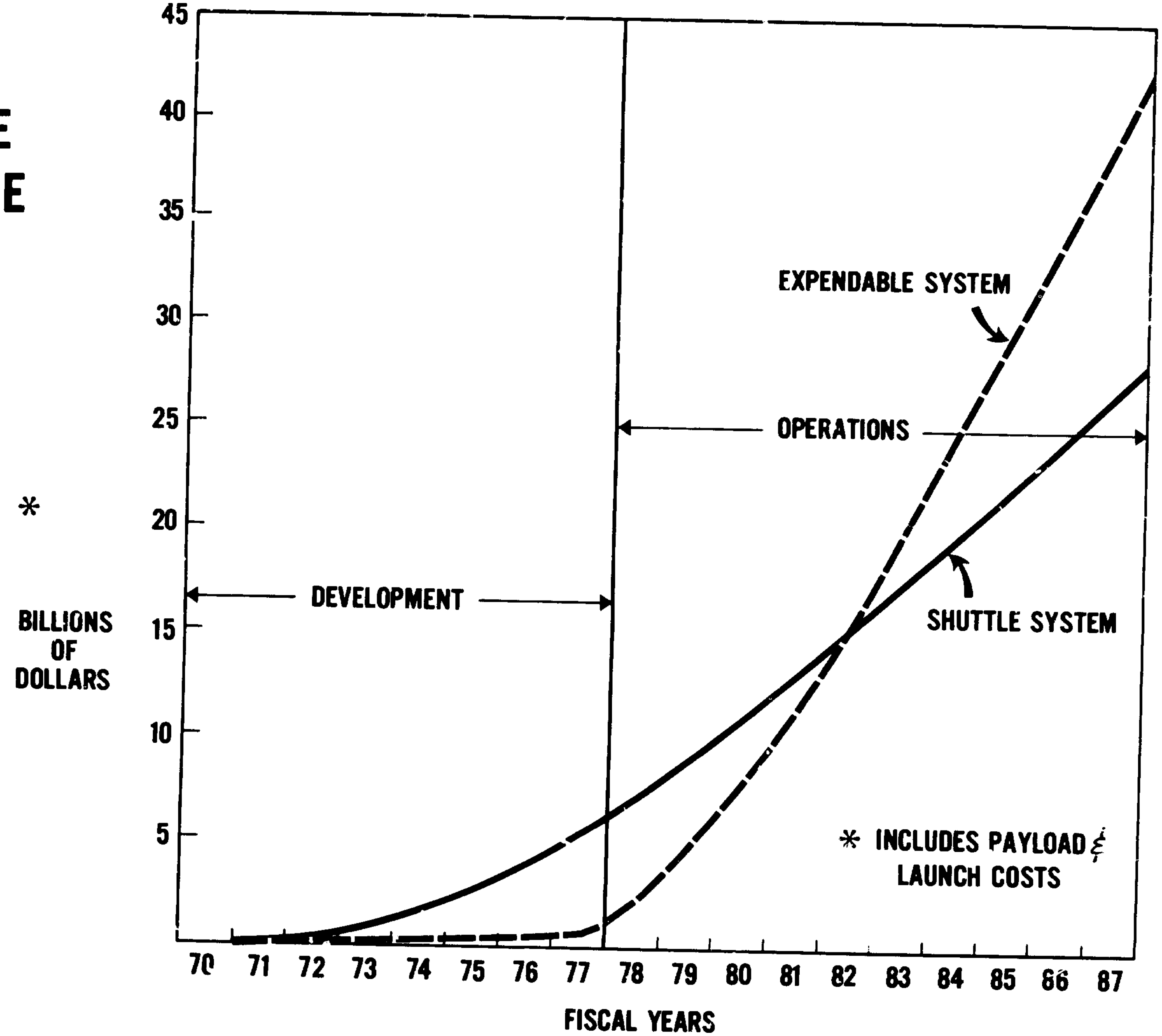


FIGURE 22

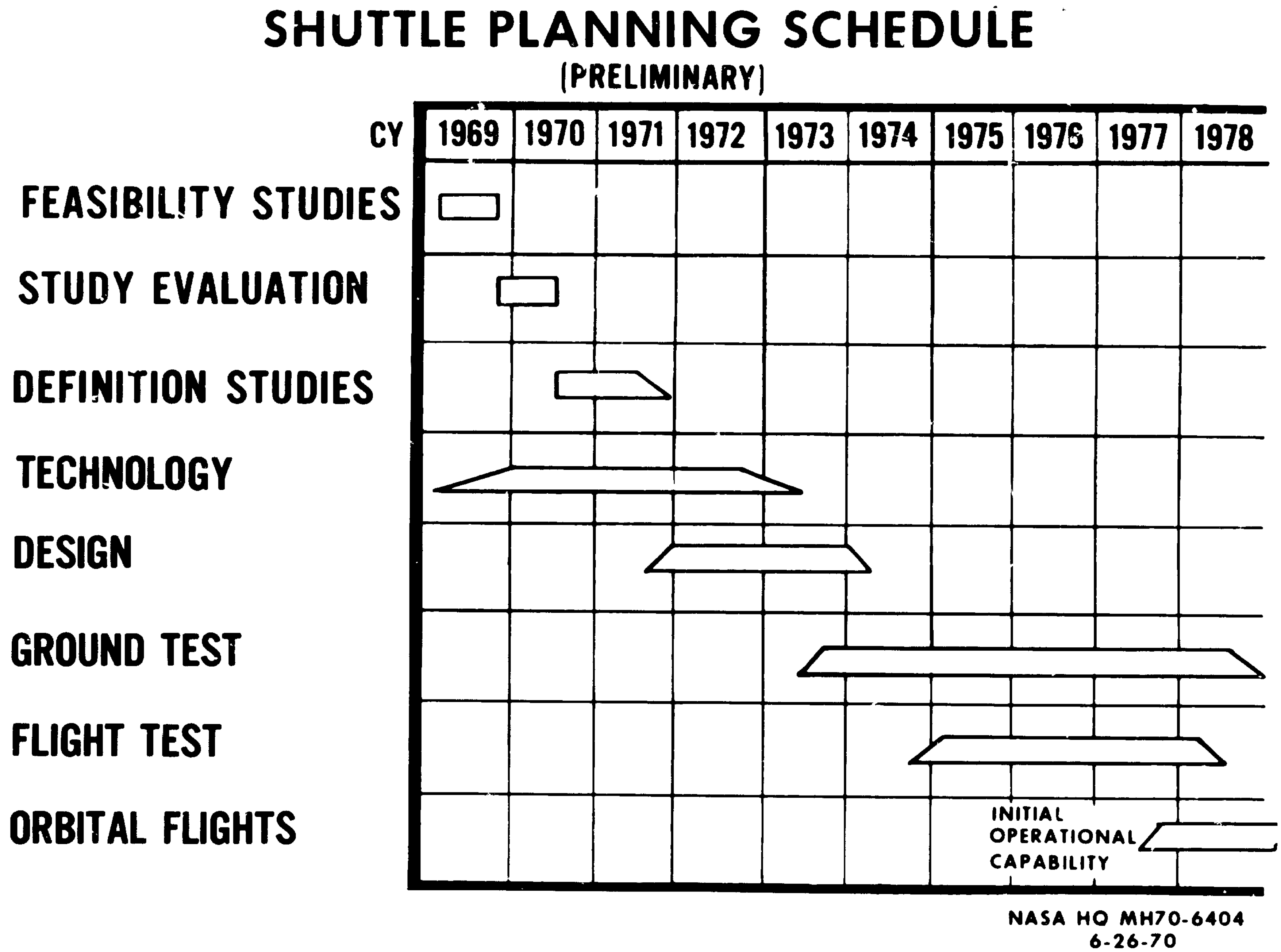


FIGURE 23

GPO 898-903